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AERATED CONCRETE ON BASIS OF VOLCANIC ROCKS WASTE AS EFFICIENT THERMAL INSULATION MATERIAL

Key words: construction materials, lightweight concrete, ecology, modern construction, thermal insulation, volcanic waste

Construction materials and particularly construction items make 50-60% of overall construction costs. Choosing of effective environmentally friendly building materials based on resource and energy-saving technologies enables to significantly reduce prime cost of construction. Raw materials for manufacturing of construction items should be environmentally friendly widespread and cheap. And therefore raw materials like water, sand and carbonate minerals (limestone, chalk, marl) as well as products derived therefrom (cement, lime) are frequently encountered in nature and easily obtained.

Additionally, waste from nonmetallic industry is valuable and very cheap raw material for manufacturing of construction materials. Particularly it relates to heat insulation and structural concretes, lightweight foam fillers etc. These wastes may be used as efficient aggregates for concrete blocks production.

The article substantiated that the use of aerated concrete based on volcanic rocks waste makes it possible to reduce construction costs, shorten the construction period, to create a residential building with more comfortable conditions.

1. Introduction

Many decades of manufacturing and exploitation of aerated concrete proved that aerated wall blocks the most lightweight from all type of concretes by ensuring sufficient strength for construction of buildings, dwelling houses, self-supporting walls, multistory framing building etc.

Aerated concrete is a class of cellular concretes, and is a material with equally distributed air closed pores over the volume. This kind of structure defines a number of physical and technical

characteristics that make cellular concrete highly effective, warm building material because the air naturally is the best thermal insulator. Aerated concrete - a high-quality, eco-friendly building material. For the first time it was made about 80 years ago and still due to its superiorities is constantly applied. Simultaneously, there has been a very significant change in the replacement of burnt clay bricks by concrete masonry units. It appears that the usage of aerated concrete block masonry may become more common in the coming years.

Enveloping structures made from dimension stones and lightweight concrete on basis of natural porous aggregates are widely used in Armenia and capable to ensure thermal resistance and technical specifications required for thermal and seismic efficiency of walls only with considerable thickness of walls – 0.8 – 1.2 m. Which results to unprecedented grow of consumption of materials and therefore it affects to increase of buildings and structures weights, as well as to decrease of seismic stability. The last is quite important aspect in such country like Armenia where seismic risk level is one of the highest.

Being one of the largest consumers of energy resources, the housing sector spends 2-3 times more heat for warming of residential and other premises comparing with industrialized countries. This is firstly conditioned with reduced RA requirements to the index of thermal resistance of the walls and, secondly derives from insufficiency of provision even these requirements. The problem of enveloping materials in the Armenia exists long time, since concrete produced on all varieties of natural resources does not meet the increased requirements for thermal insulation.

Additionally, due to the depletion of natural deposits of high-quality raw materials, it become important to utilize new and innovative types of mineral resources and industrial waste in the manufacturing of efficient building materials and products. Resources of Armenia although enormous, yet they are limited, and we should take care where, when and how these resources can be used in the most efficient way.

The question of integrated use of non-metallic raw materials especially volcanic rocks (tufo) is quite urgent nowadays. It conditioned with large volume of tufo extraction and production waste formed in process of mining and treatment of this volcanic rocks. In Armenia the volume of

volcanic waste exceeds 2 million m³/p.a. and make of 60% of overall mined rock mass. The most of production waste is formed basically due to natural fissuring of rocks (up to 40%) and fines formation that take place in process of rocks cutting during its mining and treatment (20%-25%). Currently, over 100 million m³ volcanic production wastes occupy a large territory of Armenia that deteriorates ecological and economic conditions of the country. The occupation of usable lands for disposal of non-metallic industry wastes may lead to irrecoverable consequences [1].

Purpose of work is development of gas-silicate compounds on the basis of volcanic rocks, as well as reducing material capacity and energy consumption of building complex by embedding into process waste of non-metal industry as main raw material and by using energy-efficient technologies of production, which leads to limitation of heat loss in the process of exploitative of buildings and structures through improving the thermal insulation properties of the material used for the production of wall structures.

2. Aerated concrete advantages and application in construction

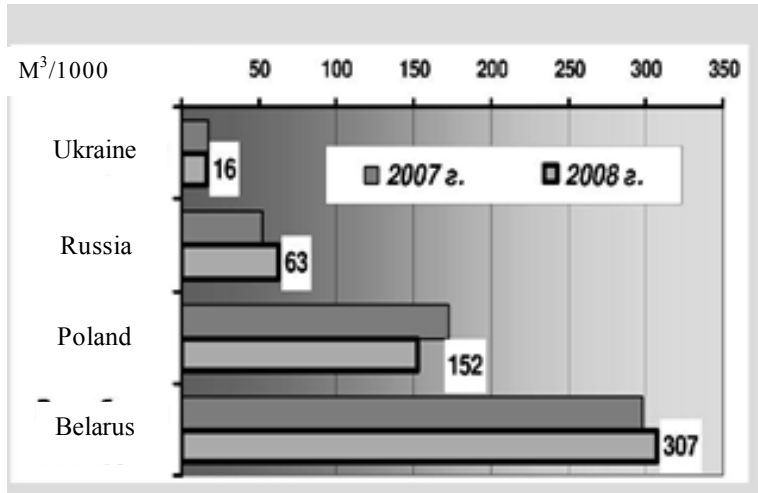
In general, aerated concrete is quite simple for exploitation and easy to handle, so it facilitates building of walls of complex configuration. Besides its heat insulating features aerated concrete also has quite strong sound insulation qualities, it is fireproof and environmentally friendly material so it will not burn or give off toxic fumes. The cost of aerated blocks sufficiently competitive with brick, wood and other wall materials costs.

AAC was developed in 1924 by a Swedish architect, who was looking for an alternate building material with properties similar to that of wood – good thermal insulation, solid structure and easy to work with – but without the disadvantage of combustibility, decay and termite damage.

It has been refined into a high-thermal insulating concrete-based material used for both internal and external construction. Currently, aerated concrete items are the most common building materials with over 300 plants worldwide. In CIS countries the technology of AAC production

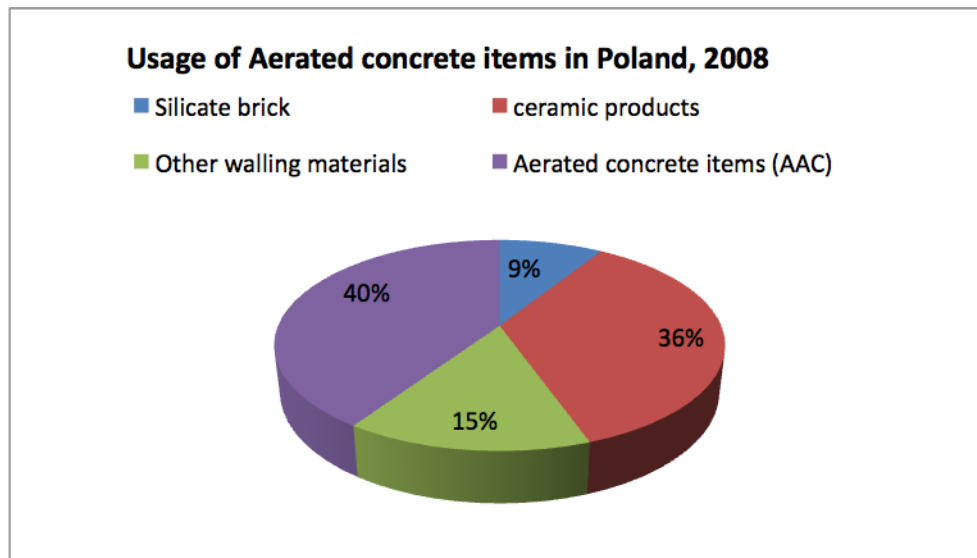
was introduced in 1950s and led to large-scale manufacturing in Belarus, Ukraine and Russia (See Figure 1).

Figure 1. Current volume of AAC structures production in Post-Soviet countries [2]



Poland continues production of AAC items with increasing volume. In 2007 they manufactured 5.55 mln.m³ and in 2008 – 4.9 mln.m³ (see Figure 2).

Figure 2. Use of walling materials in the construction of buildings in Poland (%)



In comparison with other wall materials particularly with brick and wood, aerated concrete blocks combines insulation and structural capability in one material for walls, floors, and roofs.

Its light weight/cellular properties make it easy to cut, shape size and accept nails and screws readily, and allow it to be routed to create chases for electrical conduits and small diameter plumbing runs.

Aerated concrete structures are produced with average density 300-600kg/m³ and strength 1.5-5.0 MPa, which enable its usage as wall structure and external envelope items. In comparison with bricks and claydite-concrete blocks the thermal conductivity of AAC is 3-4 times lower. It can be used for one layer envelope items in all climatic conditions [3].

Figure 3 gives a comparison of the block density of a variety of masonry units.

Legend:

ACB: Aerated Concrete Block, TMB: Table moulded

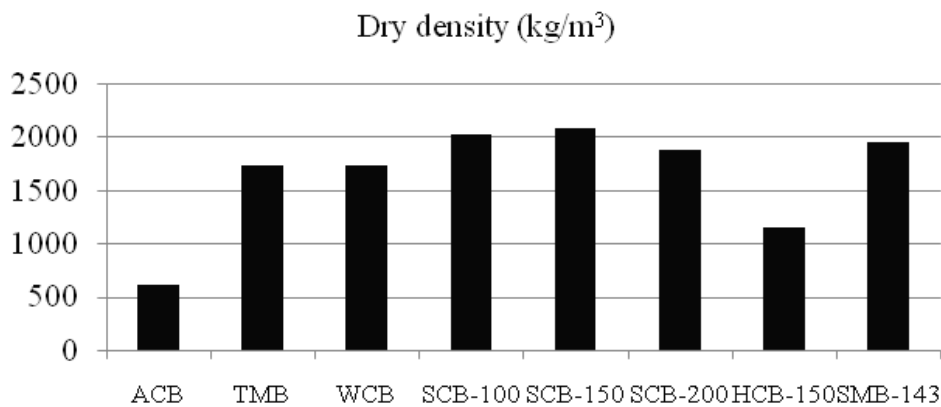
brick, WCB: Wire cut brick

SCB: Solid concrete block (150mm and 200mm thick)

HCB: Hollow concrete block (150mm thick)

SMB: Stabilized mud blocks, 8% cement (143mm thick)

Figure. 3 Comparison of dry density of different types of units [4]



The use of aerated concrete with 500-600 kg / m³ density, allows constructing buildings in average climate zone with the wall thickness 20-24 cm and a mass 120-180 kg /m², which is up to two times less in comparison with lightweight concrete of 1100 kg / m³ density, applied in

production of prefabricated houses (Table 2). In result the cost of one m² produced wall is greatly reduced (Table 2) [5].

Table 2. Required tackiness of wall to ensure 2.2 thermal resistances for various materials

Raw material	Density, kg/m ³	Compressive strength, MPa	Thermal conductivity coefficient	Thickness of wall, m
			W/ m. ⁰ C	
Slag concrete	1400	10.0	0.405	0.88
	1300	9.0	0.407	0.77
	1200	7.5	0.349	0.66
Granulated concrete	950	15.0	0.211	0.42
	850	13.0	0.177	0.35
	780	7.5	0.162	0.31
	700	5.5	0.151	0.29
Aerated concrete	1000	15.0	0.326	0.61
	900	12.0	0.256	0.48
	800	9.0	0.209	0.40
	700	7.5	0.175	0.33
	600	5.0	0.116	0.22
	500	3.5	0.105	0.20
	400	2.0	0.093	0.18
Artik tufo	1500	-	0.465	0.88
Kosh tufo	1900	-	0.640	1.21
Hoktembryan tufo	1800	-	0.582	1.10

Aerated concrete has also excellent fire resistance, it is noncombustible, it will not burn or give off toxic fumes. Due of the high dimensional accuracy, the blocks can be laid with very thin mortar joints. ACB blocks weigh lesser, the dead load is lesser on the structure and hence the structure can be designed more efficiently for a lower load which has seismic significance. Moreover, the use of AAC for load-bearing walls is quite common in low seismicity areas in Central and Northern Europe, where its thermal insulation properties, together with lightness and workability, are particularly appreciated. AAC buildings can be engineered for earthquake and hurricane prone areas, and such buildings have performed well to date. For example, the vast majority of AAC homes in the 1995 Kobe, Japan earthquake survived substantially undamaged. They also were immune from fires started during the earthquake and even acted as firebreaks. The ability of AAC structures to withstand fires and natural disasters minimizes waste, contamination to the surrounding environment, and the need for repair materials, while also lowering insurance costs.

Table 1. Comparison between aerated concrete blocks vs clay bricks [6]

Serial	Parameter	Aerated concrete Blocks	Clay Bricks
1	Soil Consumption	Zero soil consumption. Primary raw material for AAC blocks is fly ash. This fly ash is industrial waste generated by coal-based thermal power plants.	One sq ft of carpet area with clay brick walling will consume 25.5 kg of top soil.
2	Fuel Consumption	One sq ft of carpet area with AAC blocks will consume 1 kg of coal.	One sq ft of carpet area with clay bricks will consume 8 kg of coal.
3	CO ₂ Emission	One sq ft of carpet area will emit 2.2 kg of CO ₂ .	One sq ft of carpet area will emit 17.6 kg of CO ₂ .
4	Labour	Organized sector with proper HR practices.	Unorganized sector with rampant use of child labour.

5	Production Facility	State-of-the-art factory facility.	Unhealthy working conditions due to toxic gases.
6	Tax Contribution	Contributes to government taxes in form of Central Excise, VAT and Octroi.	Does not contribute to government exchequer.
7	Size	600 / 625 mm x 200 / 240 mm x 100-300 mm	225 mm x 100 mm x 65 mm
8	Variation in Size	1.5 mm (+/-)	5 mm (+/-)
9	Compressive Strength	3-4 N/m ²	2.5-3 N/m ²
10	Dry Density	550-700 kg/m ³	1800 kg/ m ³
11	Fire Resistance (8" wall)	Up to 7 hours.	Around 2 hours
12	Cost Benefit	Reduction in dead weight leading to savings in steel and concrete.	None
13	Energy Saving	Approximately 30% for heating and cooling.	None

Additionally, AAC consumes a relatively small amount of raw material in comparison with the amount of finished product produced. Because AAC is approximately 80% air, the finished product is up to 5 times the volume of the raw material consumed in its production. It reduces noise, pollution and improves indoor air quality. Due to its millions of independent air cells, which dampen sound transmission, AAC has excellent sound insulation and absorption qualities. Moreover, because AAC construction has very low air infiltration and is mold resistant, indoor air quality of AAC structures is improved relative to competitors. AAC's performance as both a structural and insulation material also eliminates the need for other materials (like fiberglass insulation) that may contribute to poor indoor air quality [7].

3. Raw materials and technology

Aerated concrete is a mixture of cement, quick lime, water, and sand that expands by adding expansion agent- aluminium powder. The reaction between aluminium and concrete produces microscopic hydrogen bubbles, expanding the concrete up to about five times its original volume. After evaporation of the hydrogen, aerated concrete usually is cut to size and form and steamcured in a pressurized chamber (autoclave). Steam curing of specimens in these autoclaves at a pressure of several times the atmospheric one ensures that hydrothermal conditions are maintained. The result of this process is a lightweight material characterized by a fine cellular structure made of calcium silicate hydrate matrix, which provides excellent properties of thermal insulation and fire resistance. These characteristics justify the interest for AAC as a construction material, both for nonstructural and structural applications. As is well known, the absorption of water, due to the porous nature of AAC, reduces the structural performance and specific detailing is then required in order to guarantee a satisfactory static behavior.

Quick lime (CaO) – According to research done in 1930s it was proved that under certain conditions quick lime undergoes hydration curing process, i.e. curing occurs by interaction with water and formation calcium hydroxide, just as Portland cement or gypsum hardening process take place. The fine quick lime has a number of advantages in the manufacture of mortars and concretes. Moreover, milled quicklime is characterized by less water demand in comparison with hydrated lime [8]. The required placeability of quicklime based mortars or concrete could be obtained with reduced amount of water. Reducing the water demand of mortars and concrete mixtures makes possible to increases strength of concrete during curing process (see Table 1). Therefore, it makes possible to replace the expensive Portland cement with cheaper non-clinker binder.

Table 2. Aerated concrete strength relation with average density [9]

Average density, kg/m ³	Compressive strength dependence on binder type (R _c), MPa			
	Cement	Lime	Fly ash	Slag

300	-	1-1.5	-	-
400	-	1.5-2	-	-
500	1.5-2.5	2.5-4	-	-
600	2-3.5	4-5.5	3	2.5
700	4.4.5	5.5-7.5	4	3.5
800	5.5	7.5-9.5	5	4.5
900	6.5	9.5-12	7	6
1000	8	12-15	9	8
1100	10	-	12	11
1200	13	-	16	14

Thus, milled quicklime mortars and concrete have following advantages:

- Introduction of quicklime into mortars and concrete accelerates conjunction and hardening processes. Based on characteristics of lime the mortars and concrete mixture conjunct within 30-50 minutes additionally hardening take place 50-100 times faster than similar process in lime putty.
- The energy produced from hydration of milled quicklime could be efficiently used by accelerating evaporation process of water from curing mortars and concretes and therefore by supporting hardening process of the concrete. $\text{CaO} + \text{H}_2\text{O} = \text{Ca}(\text{OH})_2 + \text{Q}$

Volcanic rock production waste (tufo) -In the production and mining process the tufo formed a lot of waste products, which occupy large areas and its disposal has economic and ecological significance. These wastes are very cheap and valuable raw material for obtaining non-clinker binders and cementless concretes. Half crystal structure of Armenian volcanic rocks, consisting of crystals and glass with different percentages, allows to create on their basis thermodynamic active systems, which being supply with heat create structural links through the hydration hardening process.

Though chemical composition of volcanic rocks alters in wide range, however dominating oxides in these materials are silica and aluminium oxide (70-80%). In the mixture with water and lime those forms thermodynamical inconstant system, which energy depends on reactivity of the raw materials [1].

Table 4. Chemical composition of volcanic rock % (tufo)

%	Slag	Pumice	Perlite	Artik tufo	Ani tufo
SiO ₂	57.55	67.52	72.64	65.15	67.83
Al ₂ O ₃	17.14	15.42	15.56	16.96	14.97
Fe ₂ O ₃	7.47	4.22	1.36	4.20	3.30
TiO ₂	1.09	0.42	0.07	0.67	0.15
CaO	5.85	2.03	1.31	3.11	3.09
MgO	2.78	0.74	0.45	1.42	0.38
SO ₃	0.00	0.13	0.07	0.51	0.45

Mutable state of volcanic glass gives to the system sufficient energy potential accumulated in the material, which allows completing hardening process through a chemical reaction. Under the certain conditions, the excess energy can be used efficiently by synthesis of water-resistant materials.

Reaction activity of volcanic materials could be increased by transferring them into more thermodynamic unstable condition by means of fine grinding. The most thermodynamically unstable state of the system corresponds to specific surface area that varies in the range of 400-500 m²/kg.

Expansion agent - Gas-forming chemicals are mixed into lime or cement mortar during the liquid or plastic stage, resulting in a mass of increased volume and when the gas escapes, leaves a porous structure. Aluminium powder, hydrogen peroxide/bleaching powder and calcium carbide liberate hydrogen, oxygen and acetylene, respectively. Among these, aluminium powder is the most commonly used aerating agent [10]. To be classified as a foamed concrete the air content of the concrete must be greater than 25 per cent. Air can be introduced into the concrete mix to form foamed slurry by using following principal methods: involve a foam producing admixture being

added to the other constituents in a high shear mixer (J.Newman and B.S. Choo, 2003). In result of interfusion the aluminium powder react with Ca(OH)_2 component and following reaction take place:

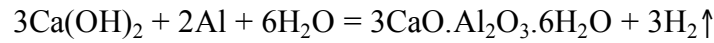


Table 5 shows optimal composition of cellular concrete obtained and tested in the laboratory.

Table 5. Physical and mechanical characteristics of cementless cellular concrete

Quick lime, %	Gypsum %	Aluminium powder, %	Physical and mechanical characteristics	
			Density, kg/m^3	Compressive strength, MPa
20	2.5	0.05	1107	5.5
20	2.5	0.03	1248	7.0
25	2.5	0.05	1049	5.0
25	2.5	0.03	1200	7.0

4. Conclusion

Concrete is one of the most widely used building materials in modern construction of Armenia and therefore research and improvement of its properties as well as improvement durability of this material is still actual objective set forth in long-term prospective.

Increasing attention to energy-efficient buildings is now supporting the adoption of a material with such characteristics also in higher seismicity regions like Armenia.

The raw materials for the production of the aerated concrete should be widespread and eco-friendly. This type of materials can be water, quicklime and wastes from volcanic production.

The research will reveal the best compositions for thermal insulating concrete production by introducing as main raw material the waste accumulated from volcanic rock mining and treatment processes, which will tackle existing ecological issues in Armenia.

Finally, research will develop a form of concrete with a high strength to density ratio: low density for high materials efficiency and high compressive strength with the elimination of autoclaving.

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